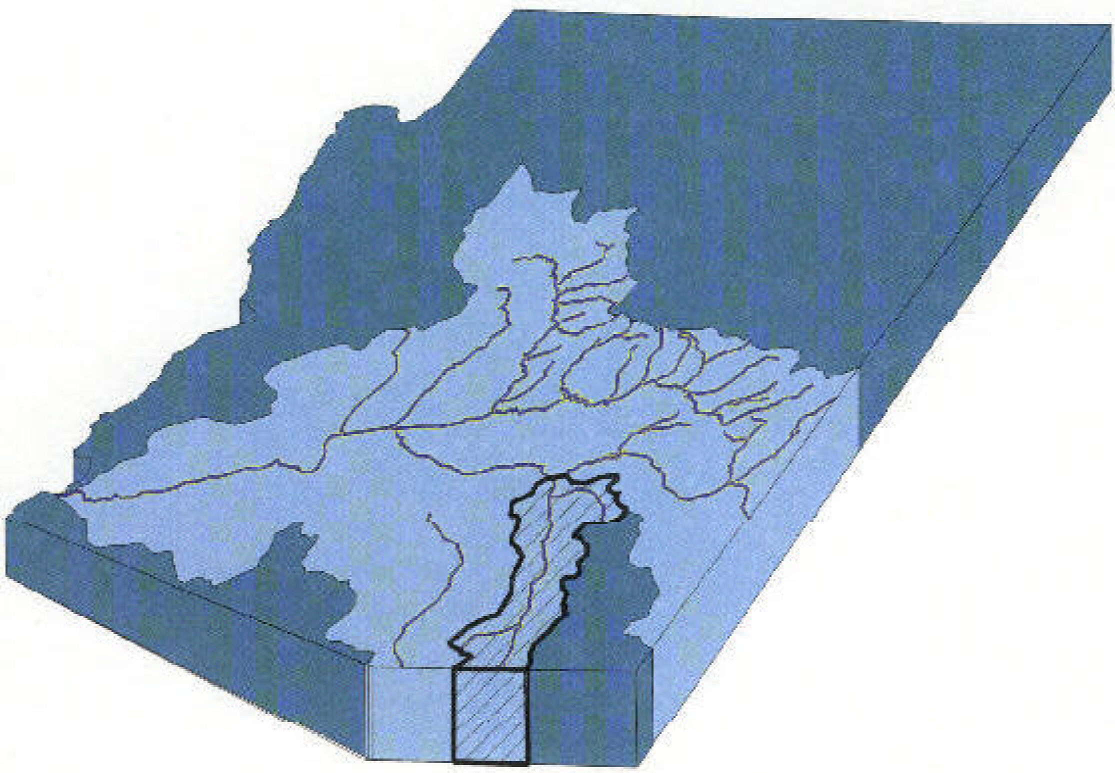
SUBFLOW TECHNICAL REPORT
SAN PEDRO RIVER WATERSHED

In Re The General Adjudication Of The
Gila River System And Source



Arizona Department of Water Resources

March 29, 2002

N O T I C E

On March 29, 2002 the Arizona Department of Water Resources filed a report entitled "Subflow Technical Report, San Pedro River Watershed." The methodologies proposed in this report represent the Department's recommendations to the court for the Gila River System and Source adjudication. The Department's recommendations are subject to further comment by the parties, and review by the adjudication court.

PLEASE KEEP IN MIND THE METHODOLOGIES RECOMMENDED IN THE DEPARTMENT'S SUBFLOW TECHNICAL REPORT HAVE NOT BEEN ADOPTED BY THE ADJUDICATION COURT.

(April 3, 2002)

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

CHAPTER 1: INTRODUCTION

This report has been prepared by the Arizona Department of Water Resources (Department) at the request of the trial court in the general adjudication of the Gila River System and Source (Gila River adjudication). Minute Entry, Jan. 9, 2002. It addresses issues relating to the distinction between surface water and groundwater that have been before the trial court as well as the Arizona Supreme Court on four separate occasions between 1988 and 2000.

Water rights in Arizona are subject to a bifurcated system that differentiates groundwater from surface water. Surface water is subject to the doctrines of prior appropriation and beneficial use, whereas percolating groundwater is not appropriable and may be pumped by the overlying landowner subject to the doctrine of reasonable use, and the federal reserved water rights doctrine. *In re the Adjudication of all Rights to Use Water in the Gila River System and Source,* 198 Ariz. 330, 334, 9 P.3d 1069, 1074 (2000) (*Gila IV*). Arizona's bifurcated system is complicated by the fact that there is no clear distinction between surface water and groundwater in certain areas close to streams.

Arizona's bifurcated system has generated several years of litigation within the context of the Gila River adjudication. Simply because water is located below the surface, it may not necessarily be groundwater but instead may be appropriable subflow. Since 1931, courts have recognized that pumping water from wells may have a direct and appreciable impact on stream flows if those wells are in the vicinity of the stream. *Maricopa County Municipal Water Conservation Dist. No. One v. Southwest Cotton Co.*, 39 Ariz. 65, 4 P.2d 369 (1931) (*Southwest Cotton*). Identifying those wells has been problematic.

Early in the Gila River adjudication, the issue of identifying wells pumping appropriable subflow was before the trial court to determine whether those wells should be included in the adjudication. In 1987, the trial court held hearings on the relationship between surface water and groundwater, and in 1988 the trial court concluded that certain wells withdrawing water from the younger alluvium of a stream basin should be presumed to be pumping appropriable subflow if the volume of stream depletion was 50% or more as the result of 90 days of continuous pumping. In 1993, the Arizona Supreme Court determined that the trial court erred in adopting the 50%/90 day test, and the matter was remanded to the trial court "to take evidence and, by applying the principles contained in this opinion, determine the criteria for separating appropriable subflow from percolating groundwater." *In re the Adjudication of all Rights to Use Water in the Gila River System and Source,* 175 Ariz. 382, 394, 857 P.2d 1236, 1248 (2000) (*Gila II*).

Upon remand from the Arizona Supreme Court, the trial court engaged in a lengthy hearing process, involving expert testimony on complex hydrogeologic principles, that culminated in a 66-page detailed order with 36 additional pages of exhibits. *Gila IV,* 198 Ariz. at 336, 9 P.3d at 1075. The trial court applied the criteria described in *Gila II* and concluded that the saturated floodplain Holocene alluvium was the "most credible" subflow zone, that wells located outside the subflow zone could also pump subflow if their cones of depression intercepted the subflow zone, and that wells should be subject to a *de minimis* standard even though they may be pumping subflow. Trial Court Order, June 30, 1994 at pp. 58-62. The matter was again taken before the Arizona Supreme Court, and in 2000 the Court affirmed the trial court's June 30, 1994 order after remand "in all respects." The Court stated:

> We affirm the trial court's order after remand in all respects. The subflow zone is defined as the saturated floodplain Holocene alluvium. DWR, in turn, will determine the specific parameters of that zone in a particular area by evaluating all of the applicable and measurable criteria set forth in the trial court's order and any other relevant factors. See ¶¶ 33-35, *supra*. All wells located in the lateral limits of the subflow zone are subject to this adjudication. In addition, all wells located outside the subflow zone that are pumping water from a stream or its subflow, as determined by DWR's analysis of the well's cone of depression, are included in this adjudication. Finally, wells that, though pumping subflow, have a de minimus [*sic*] effect on the river system may be excluded from the adjudication based on rational guidelines for such an exclusion as proposed by DWR and adopted by the trial court.

Gila IV, 198 Ariz. at 344, 9 P.3d at 1083.

By Minute Entry dated January 9, 2002, the trial court requested that the Department prepare a report that identifies and describes "the procedures and processes that it proposes to use to establish the limits of the subflow zone within the San Pedro River watershed." As directed by *Gila IV*, the trial court requested that the report address the following: procedures for determining the lateral limits of the subflow zone, a test for determining if a well's cone of depression is withdrawing water from the subflow zone, and rational guidelines for determining whether a particular well, though pumping subflow, has a *de minimis* effect on the river system. In response to the trial court's request, the Department prepared this report.

There are six chapters in this report. The methodologies that the Department proposes to use are described in Chapters 2, 3 and 4. In Chapter 2, the Department discusses steps for delineating the lateral limits of the jurisdictional subflow zone. In Chapter 3, the Department discusses steps for implementing a cone of depression test. In Chapter 4, the Department recommends guidelines for addressing *de minimis* uses within the adjudication. In Chapter 5, the Department summarizes its recommended approaches, and discusses how they may be implemented in the future. In Chapter 6, the Department lists the technical references cited in this report.

CHAPTER 2: SUBFLOW ZONE

This chapter describes the Department's proposed methodology for delineating the jurisdictional subflow zone within the San Pedro River watershed. As required by the Arizona Supreme Court in *Gila IV*, this methodology uses those criteria geologically and hydrologically appropriate for a subflow determination in this watershed. And, as requested by the trial court, this methodology "addresses the appropriate use, if any, of each of the criterion listed in Gila IV, as well as any other relevant factors that will be helpful in insuring that ADWR's subflow zone determination is completed using all reasonable means to arrive at results that are as accurate as possible."

The trial court also requested that the Department include a method to include "both perennial and intermittent streams as part of the subflow analysis, including streams that historically contained perennial or intermittent flows, but which now are ephemeral due to development and other human initiated actions." Additionally, the trial court requested that the Department include "effluent fed" streams. These streams are included in the Department's analysis.

The Department proposes to use five steps to delineate the jurisdictional subflow zone for San Pedro River watershed. The Department will determine the location of:

- Perennial streams;
- Intermittent streams;
- Effluent fed streams;
- Lateral extent of the floodplain Holocene alluvium; and
- Saturated portion of the floodplain Holocene alluvium.

Each of these steps is described below. These steps may be applied for all watersheds within the Gila River adjudication, including the San Pedro River watershed.

2.1 LOCATION OF PERENNIAL STREAMS

To determine the location of perennial streams under both predevelopment and current conditions, the Department conducted an extensive literature search to identify Arizona streamflow maps. A total of eleven published streamflow maps were identified that cover all or portions of the Gila River adjudication area. A list of the maps identified by the Department and the data sources that were used to delineate stream reaches are presented in Appendix A.

The published streamflow maps identified by the Department can be divided into two general groups, those that identify predevelopment perennial streams and those that identify recent perennial, intermittent, or effluent fed streams. To determine the location of the predevelopment perennial reaches, the Department proposes to use the U.S. Geological Survey (USGS) Hydrologic Investigations Atlas entitled *Predevelopment Hydrologic Conditions in the Alluvial Basins of Arizona and Adjacent Parts of California and New Mexico*. This atlas was published in 1986, and was prepared by G.W. Freethey and T.W. Anderson as part of the Southwest Alluvial Basins, Regional Aquifer Systems Analysis (Swab/RASA) Project. One of the goals of the Swab/RASA Project was "an overall assessment of hydrologic conditions that existed prior to man's activities that might have altered the natural hydrologic systems." The atlas is comprised of three maps that, when combined, cover the entire Gila River adjudication area as well as minor areas outside of the adjudication. Copies of the maps are provided in this report as Plates 1, 2 and 3.

The USGS atlas shows the location of predevelopment perennial streams as well as predevelopment water level contours. These predevelopment hydrologic conditions were based on a variety of sources including:

- Historic accounts;
- Field data collected by the USGS and other agencies from the early 1900s to about 1940 "which precedes the period of greatest development;"
- Recent data "for basins where development is minor and long term changes in water levels can be assumed to be small and negligible;" and
- Numerical ground water models.

A list of references used in preparation of the USGS atlas is provided on Plate 2.

The Department is aware that perennial stream reaches currently exist in the adjudication area that are not shown on the USGS predevelopment maps, either because they did not exist under predevelopment conditions or they were not identified by the USGS. To identify these reaches, the Department proposes to use a 1993 perennial stream map prepared by Valencia and others of the Arizona Game and Fish Department

(AGFD) as part of the Statewide Riparian Inventory and Mapping (SRIM) Project. The perennial reaches identified by the AGFD are shown in Figure 1, and a copy of the accompanying technical report is included in Appendix B. Included in the 1993 AGFD report are definitions for perennial, intermittent, and ephemeral streams that were used by the Department for this report.

The 1993 AGFD map is based on a 1981 AGFD perennial stream map by Brown and others that was later revised based on consultation with the Department, U.S. Forest Service (USFS), Bureau of Land Management (BLM), Arizona Department of Environmental Quality (ADEQ), private sector hydrologists, and academicians. Using Graphic Information System (GIS) technology, the Department proposes to overlay the recent AGFD perennial stream map on the USGS predevelopment maps. The recent perennial reaches would then be combined with the predevelopment perennial reaches to create a perennial stream map.

2.2 LOCATION OF INTERMITTENT STREAMS

Due to a lack of historical data, the Department was unable to identify a published map that depicts the location of *predevelopment* intermittent streams. However, the Department did identify a 1997 map by Wahl and others of the AGFD that shows the recent location of intermittent streams in Arizona. This map was prepared during the last phase of the SRIM Project and was based on the identification of intermittent streams on topographic maps by staff of the BLM, USFS, National Park Service (NPS), and AGFD. Some of the intermittent reaches depicted on the AGFD map are questionable and believed by the Department to actually be ephemeral based on recent data from USGS stream gages. As the adjudication proceeds into those areas, the Department recommends that the location of current intermittent reaches be further evaluated. The intermittent reaches identified by the AGFD are shown in Figure 2, and a copy of the accompanying technical report is provided in Appendix C.

The Department is aware that intermittent stream reaches currently exist that were not previously identified as perennial, and that are not currently perennial. The Department proposes that these recent intermittent reaches be identified by overlying the 1997 AGFD map onto the perennial map prepared under section 2.1. The end product would be a composite map that shows the predevelopment perennial stream reaches identified by the USGS combined with recent perennial and intermittent stream reaches identified by the AGFD.

2.3 LOCATION OF EFFLUENT FED STREAMS

A list of the major and minor effluent fed reaches in Arizona was developed by the ADEQ as part of its surface water quality rules (A.A.C. R18-11-113, Effluent Dependent Waters). A copy of the rule is presented in Appendix D. According to the ADEQ, there are three major effluent fed stream reaches located within the Gila River adjudication area:

- Santa Cruz River below the Nogales International Waste Water Treatment Plant (WWTP);
- Santa Cruz River below Tucson's Roger Road WWTP; and
- Gila River below Phoenix's 91st Avenue WWTP.

Except for the reach below Tucson, the USGS predevelopment maps indicate that the entire length of these effluent fed streams was perennial during predevelopment conditions. In addition to the major reaches listed above, ADEQ identified several minor effluent fed streams that occur below the WWTPs of several towns including Mt. Lemmon and Tombstone that are located in the San Pedro River watershed. The location and length of the effluent fed reaches are shown in Figure 3 based on GIS data the Department received from the ADEQ. The Department proposes to compare this figure with the composite stream map prepared under section 2.2, and those effluent fed reaches not already identified as perennial or intermittent would be added to the map and designated accordingly.

It should be noted that not all effluent fed streams would necessarily have a jurisdictional subflow zone adjacent to and beneath them. One of the characteristics of the jurisdictional subflow zone is the existence of a hydraulic connection between the subflow and the stream. Due to the elevated nutrient and/or organic content of most effluent, it is common for low permeability "clogging layers" to form along the bed of effluent fed streams. These layers can restrict the seepage of streamflow and, as a result, can cause the sediments beneath the stream to be unsaturated. Under these conditions, effluent would seep downward as unsaturated flow until it reaches an underlying saturated zone. The area adjacent to and beneath such streams would not, by definition, be characteristic of a jurisdictional subflow zone due to the lack of a hydraulic connection between the subflow and the stream.

Bouwer (1978) states the following regarding clogging layers at page 289 in his textbook on hydrology:

> Clogging is primarily caused by settling of sediment, straining of suspended material as water moves through the sediment layer and into the soil, and bacterial and other biological action... When sediment begins to accumulate on top of the soil...the fine particles no longer move into the bottom material but are strained out on top of the sediment layer where they contribute to the hydraulic resistance of the clogging layer. Clogging thus is primarily a surface phenomenon that rarely extends more than 10 cm into the soil and often is restricted to the top centimeter or less... Continued clogging eventually reduces infiltration rates to only a fraction (one tenth or less, for example) of the original infiltration rate... Rice (1974) reported serious clogging with infiltration of secondary sewage effluent if it contained more than 10 mg/l suspended solids.

Further discussion of clogging layers is found in the hydrology textbook by Todd (1980).

Detailed geologic and hydrologic data are needed to confirm the presence or absence of clogging layers along effluent fed streams, and the occurrence of unsaturated flow beneath these streams. The Department believes these data are generally unavailable at this time and would require considerable time and resources to collect in the future. Two of the three major effluent fed streams in the Gila River adjudication were previously perennial and would already be included in the composite map following the methodology described in section 2.1. For the effluent fed streams that were not previously perennial, or recently perennial or intermittent, the Department proposes that it be assumed that the sediments immediately beneath these reaches are unsaturated due to clogging layers. These reaches would, therefore, not be included in the methodology to determine the jurisdictional subflow zone.

2.4 LOCATION OF LATERAL EXTENT OF THE FLOODPLAIN HOLOCENE ALLUVIUM

Defining the lateral extent of the floodplain Holocene alluvium requires several steps. The first step would be to identify and obtain copies of published surficial geology maps for the areas with perennial and intermittent streams. The second step would be to review the identified maps and determine those which delineate floodplain Holocene alluvium. The third step would be to evaluate the adequacy of the Holocene maps using a set of predefined criteria. Based on this adequacy evaluation and professional judgment, the fourth and final step would be to select the best available Holocene map to define the lateral extent of the floodplain Holocene alluvium. Further discussion of these steps is provided below along with an example of how the steps would be applied to the Sierra Vista subwatershed of the San Pedro River watershed.

The Department proposes to use two primary data sources to identify published surficial geology maps, the Arizona Geological Survey (AGS) and the USGS. Both of these agencies have developed computerized databases of Arizona geology maps. At the Department's request, the AGS searched its database and identified approximately 400 maps in the Gila River adjudication area that it believed could have useful data on the floodplain Holocene alluvium. The USGS map database is available on-line at http://ngmdb.usgs.gov and can be easily searched by inputting the coordinates of an area of interest. Although the USGS website provides a ready source of geology maps, the maps identified on-line would need to be reviewed to determine whether they provide Holocene data.

Using the map databases of the AGS and the USGS, the Department next proposes to develop a list of all published Holocene maps for a given area. Published maps are subject to peer review, which improves the reliability of the maps. The adequacy of the listed maps for the purpose of this report would then be evaluated using four criteria:

- Field work;
- Map coverage;
- Dating methods; and
- Map scale.

The reasons for selecting these criteria are described below.

In general, the Department believes a Holocene map is more adequate for defining the jurisdictional subflow zone if field work was conducted by its author; if it covers the entire subwatershed or watershed being adjudicated; if a variety of methods were used to date the floodplain Holocene alluvium; and, if it was mapped at a relatively small scale (typically less than 1:150,000). Field work is important to identify floodplain Holocene alluvium, particularly in areas where the floodplain is relatively wide and topographic maps and aerial photography are less useful in differentiating geologic units. Regarding map coverage, the use of a single map for a particular study area avoids the potential for inconsistencies in mapping methods used by different geologists. A summary of methods that can be used to date Holocene deposits and the applicability, age range, and optimal resolution of these methods are presented in Plate 4, which was published by the Geological Society of America. The Department believes that, other factors being equal, the greater the variety of dating methods employed by the geologist to map the Holocene alluvium, the more adequate the map. Finally, regarding map scale, the smaller the scale of a map, the finer its resolution and generally the more accurate the location of boundaries between geologic units. The Department recommends that these criteria be used to select the best available Holocene map to determine the lateral extent of the floodplain Holocene alluvium.

To demonstrate the process described above, the Department evaluated the adequacy of ten geologic maps that delineate the lateral extent of floodplain Holocene alluvium along the San Pedro River within the Sierra Vista subwatershed. These maps were identified in the AGS and USGS databases. Table 1, included at the end of this chapter, lists the authors of these maps, and the criteria used in the Department's adequacy evaluation.

The Sierra Vista subwatershed is located in southeastern Arizona within the San Pedro River watershed. The subwatershed covers approximately 950 square miles and extends from the international border with Mexico to about 27 miles north near Fairbanks. This reach of the San Pedro River was determined by the USGS to be perennial during predevelopment conditions, and more recently by the AGFD to be either perennial or intermittent.

Figure 4 is a composite map prepared by the Department that shows the various boundaries of the floodplain Holocene alluvium delineated on the ten maps for the Sierra

Vista subwatershed. A review of the boundaries illustrates that there are several factors that affect the mapping of the floodplain Holocene alluvium. First, when the original map scale is large (*e.g.*, the 1:1,000,000 scale maps by Richard and others, 2000 and Reynolds, 1988), the location of the Holocene boundary may be found to be inaccurate when plotted on a smaller scale. Second, when the map scale is small (*e.g.*, the 1:24,000 scale maps by Demsey and Pearthree, 1994 and Moore, 1991), the location of the Holocene boundary is more irregular than when mapped at a larger scale. Also, small-scale maps are less commonly available and, in this example, the two 1:24,000 scale maps each cover less than half of the area being evaluated. Third, where the floodplain is relatively narrow (*e.g.*, between Hereford and Charleston), the different maps show remarkably similar boundaries for the floodplain Holocene alluvium. On the other hand, where the floodplain is relatively wide (*e.g.*, south of Hereford and north of Charleston) the different maps show a wide range of boundaries for the floodplain Holocene alluvium. The Department used the criteria described above to select the most suitable map.

The Department determined that the map prepared by Pool and Coes (1999) was the best available for delineating the extent of the floodplain Holocene alluvium along the San Pedro River within the Sierra Vista subwatershed. This map has a relatively small scale (approximately 1:135,000), it covers the study area completely, the floodplain Holocene alluvium was identified and field mapped by researchers referenced by the authors, and a variety of methods were used to date the Holocene deposits. Figure 5 is a map prepared by the Department that shows the lateral extent of the floodplain Holocene alluvium along the San Pedro River based on the map by Pool and Coes (1999). It should be noted that this map was printed by the Department at a scale of approximately 1:144,000. Maps used for the actual delineation of the floodplain Holocene alluvium would be evaluated at their original scale, which, in this case, is approximately 1:135,000.

2.5 LOCATION OF THE SATURATED PORTION OF THE FLOODPLAIN HOLOCENE ALLUVIUM

The next and final step in delineating the jurisdictional subflow zone is to determine that portion of the floodplain Holocene alluvium that is saturated. Determination of the saturated portion of the floodplain Holocene alluvium requires data on two subsurface conditions:

- The thickness of the floodplain Holocene alluvium; and
- The depth to the water table beneath the floodplain.

Knowing these two conditions, the portion of the floodplain Holocene alluvium that exists beneath the water table (the saturated portion) can be determined.

However, the two conditions indicated above cannot be determined with reasonable means in the San Pedro River watershed or elsewhere in the Gila River adjudication area. The thickness of the floodplain Holocene alluvium and the depth to the water table beneath the floodplain are highly variable, both spatially and temporally, and this makes the determination of saturation difficult. In many areas of the Gila River adjudication, detailed subsurface data for the floodplain simply do not exist or are limited, and additional data would have to be collected and analyzed at considerable cost and time. In the few areas where extensive subsurface data have been collected, it is often still difficult to define variations in the thickness of the Holocene alluvium across the floodplain and changes in the elevation of the water table over time. Based on these factors, and in light of the trial court's request to consider predevelopment streamflow conditions, the Department recommends that the entire lateral extent of the floodplain Holocene alluvium be assumed to be saturated for the purpose of delineating the jurisdictional subflow zone.

An example of the inherent difficulty in defining the saturated portion of the floodplain Holocene alluvium is provided below for an area that has been extensively studied. The Sierra Vista subwatershed has been, and continues to be, one of the most studied areas in Arizona by geologists and hydrologists. Plates 5 and 6, from the 1999 USGS report by Pool and Coes, illustrate the subsurface geologic data that has been collected recently by the USGS from this subwatershed.

In order to construct hydrogeologic cross-sections along the San Pedro River within the Sierra Vista watershed, the USGS drilled several new boreholes in the floodplain Holocene alluvium and logged the drill cuttings to supplement existing information from well driller's logs. A variety of geophysical data were also collected from the floodplain Holocene alluvium including:

- Surface resistivity measurements from four survey lines and over 20 sounding areas;
- Seismic readings from four survey lines; and
- Subsurface geophysical logs from at least two boreholes.

Using these lithologic and geophysical data, four hydrogeologic cross sections were constructed, three oriented perpendicular to the San Pedro River and one oriented parallel to it. In order to construct these cross sections, it was necessary to extrapolate subsurface conditions between data points. For the cross section oriented parallel to the river, the distance between data points was greater than 1 to 2 miles, and the three sections oriented perpendicular to the river were separated by more than 5 miles. The work by the USGS just described was very costly, and was partially funded by the Department. The Department has very limited resources available to continue to fund this type of work.

Based on these data, the USGS divided the floodplain Holocene alluvium in the Sierra Vista subwatershed into two stratigraphic units consisting of the older, pre-entrenchment alluvium and the overlying post-entrenchment alluvium. From their study, Pool and Coes (1999) concluded that "deposits of pre-entrenchment Holocene alluvium are as much as 20 feet thick" but "unfortunately the distribution of pre-entrenchment Holocene alluvium is not well known." Regarding the post-entrenchment Holocene alluvium, Pool and Coes (1999) stated that its thickness ranges between "only a few feet" and "less than 20" feet. Thus, even with very sophisticated and expensive geophysical and lithological data, the actual thickness of the Holocene alluvium could not be determined with any degree of certainty.

In the remainder of the San Pedro River watershed and most of the Gila River adjudication area, well driller's logs will likely be the only source, if any, of subsurface geologic data for the floodplain. The accuracy of this data is questionable. For example, relying on an interpretation of subsurface lithology from well driller's logs, Roeske and Werrell (1973) of the USGS had previously concluded that the floodplain Holocene alluvium along the San Pedro River "generally is from 40 to 100 feet thick but may be as much as 150 thick in places." The more recent subsurface data collected by the USGS in the Sierra Vista subwatershed suggests that the thickness of the floodplain Holocene alluvium in this area may be considerably less. This lack of reliable data prevents the thickness of the floodplain Holocene alluvium from being determined with any certainty.

In addition to the lack of reliable subsurface geologic data, there is a lack of reliable data concerning the depth to the water table. On this subject, Pool and Coes (1999) state at page 23:

> Water-level changes also have occurred near the San Pedro River, but water level data have not been routinely collected in the area. As a result, relations between the ground-water flow system and flow in the river before the mid-1990's are difficult to define in detail.

This lack of data is further exacerbated by the dynamic nature of the floodplain aquifer system as demonstrated by Plate 6 from Pool and Coes (1999). Plate 6 includes long-term (greater than 30-year) hydrographs for two wells, and short-term (less than 5-year) hydrographs for six wells completed in the floodplain Holocene alluvium within the Sierra Vista subwatershed. Review of the hydrographs suggests that the aquifer system beneath the floodplain is dynamic, with the water table sometimes changing rapidly in response to storm runoff events and evapotranspiration by plants, and sometimes changing slowly due to the effects of droughts and wet periods, seasonal differences, and pumping. Based on the two long-term hydrographs on Plate 6, the depth to the water table beneath the floodplain of the San Pedro River may vary by as much as 10 to 15 feet. This is a significant amount considering that the total thickness of the floodplain Holocene alluvium in this area may be only 20 to 30 feet.

Due to variations in the depth of the water table, the portion of the floodplain Holocene alluvium that is saturated changes over time, making the determination of the jurisdictional subflow zone difficult. And these variations are not unique to recent times, but apparently also occurred during predevelopment conditions. In his description of vegetation changes and arroyo cutting in southeastern Arizona, Hastings (1959) states at page 61:

> Variation occurs from one area to another during the same season; variation occurs from one season to another; wide variation can occur from one season to the same season in a different year. By way of historical illustration two descriptions of the junction of Sopori Creek with the Santa Cruz River can be cited.

One, written by Major Fergusson in 1862, talks of the "good grass" there and the "permanent water (Fergusson, 1863).

Another by J. Ross Brown in 1864, describes the same spot this way:

> There was not so much as a pool left in the Santa Cruz River from which we could satisfy our own thirst, much less water our animals... The grass is crisped, the trees are withered, the bed of the river is dry, the sap of life seems to have deserted the place...

The same point in space, then, varies in time.

Hastings and Turner (1965) at page 37 further describe variations in predevelopment hydrologic conditions for arid and semiarid regions:

> In summary, the valleys were wetter and more open than today, and relatively unchanneled. But the precise conditions varied from place to place and probably from time to time. As the tributary washes dumped greater or less *[sic]* amounts of debris, depending upon where heavy summer rains may have struck, the rivers had to transport varying loads of sediment at different points along their course. Channeling and filling, aggradation and degradation – all may have been going on simultaneously, in various stages of development along various parts of the stream. If this dynamic situation existed, one can be sure that the vegetation reflected it. At a given time there may have been mesquite invading, where a temporary trench had sliced through the old flood plain, draining it; mesquite dying where the plain was aggrading and marshes being developed. The old accounts present a picture that is neither homogeneous, nor static. By postulating a dynamic situation one can reconcile the variety of conditions that evidently existed.

The variety of conditions discussed above were present in the San Pedro River watershed during both predevelopment and recent times making a determination of the water levels only possible at a particular point in time.

In summary, the Department believes that an accurate determination of the saturated portion of the floodplain Holocene alluvium is impractical for three reasons:

- Difficulties in defining the thickness of the floodplain Holocene alluvium;
- The general lack of detailed and long-term water level data from the floodplain; and
- The dynamic nature of the floodplain aquifer system.

The Department, therefore, recommends that the entire lateral extent of the floodplain Holocene alluvium be assumed to be saturated for the purpose of delineating the jurisdictional subflow zone. This recommendation is consistent with the inclusion of predevelopment perennial streams in the Department's methodology for delineating the jurisdictional subflow zone as requested by the court. By definition, floodplain Holocene alluvium was saturated at some point in predevelopment time.

The five steps described above will allow the Department to identify the lateral extent of the saturated floodplain Holocene alluvium by "using all reasonable means to arrive at results that are as accurate as possible" as requested by the trial court. These steps also address "the appropriate use, if any, of each of the criterion listed in Gila IV" as further requested by the trial court.

With respect to the other criteria in *Gila IV*, they are either already addressed by the preceding steps, or cannot be determined using "reasonable means." Regarding the location of saturated floodplain, the locations of perennial and intermittent streams during both predevelopment and recent times provide an indication there was a hydraulic connection between the subflow zone and the stream, and that the floodplain alluvium at those locations was saturated. However, it is not possible to determine the depth of saturation due to limited data. Regarding the flow direction, water level elevations, gradations of water level elevations, chemical composition, and lack of hydraulic pressure from tributary aquifer and basin fill recharge, these factors were already taken into account by the trial court when it concluded that the subflow zone should be determined by the lateral extent of the saturated floodplain Holocene alluvium.

> After consideration of flow direction, water level elevation, the gradation of water levels over a stream reach, the chemical composition if available, and lack of hydraulic pressure from tributary aquifer and basin fill recharge which is perpendicular to stream and "subflow" direction, the Court finds the most accurate of all the markers is the edge of the Holocene alluvium.

Gila IV, 198 Ariz. at 337, 9 P.3d 1069 at 1076 (2000). It would not be practicable for the Department to revisit the trial court's determination, which was based on a ten-day evidentiary hearing, a two-day 600-mile trip within the San Pedro River watershed, testimony by several experts in hydrology and geology, and a two-day supplemental evidentiary hearing. *Gila IV*, 198 Ariz. at 336, 9 P.3d at 1075 (2000). It is the Department's opinion that the methodology described in this chapter satisfies the criteria discussed by the trial court and the Arizona Supreme Court in *Gila IV*, and that this methodology may be used for all watersheds within the Gila River adjudication.

TABLE 1

PUBLISHED MAPS SHOWING EXTENT OF FLOODPLAIN HOLOCENE ALLUVIUM ALONG SAN PEDRO RIVER IN SIERRA VISTA SUBWATERSHED

REFERENCE	FIELD WORK	METHODS USED TO DATE FLOOPLAIN HOLOCENE ALLUVIUM									SUBWATERSHED COVERAGE	MAP SCALE
		Historic Records	Dendrochronology	Radiocarbon	Rock Varnish/ Weathering	Soil Chemistry	Soil Profile Development	Geomorphic Position	Stratigraphy	Fossils and Artifacts		
Richard and others (2000)	U	U	U	U	U	U	U	U	U	U	Complete	1:1,000,000
Pool and Coes (1999)[1]	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Complete	1:35,000 (approx.)
Demsey and Pearthree (1994)	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Partial	1:24,000
Moore (1991)	Yes	U	U	U	U	U	U	U	U	U	Partial	1:24,000
Reynolds (1988)[2]	U	U	U	U	U	U	U	U	U	U	Complete	1:1,000,000
Roeske and Werrell (1973)[3]	U	U	U	U	U	U	U	U	U	U	Complete	1:127,000 (approx.)
Brown and others (1966)[3]	Yes	U	U	U	U	U	U	U	U	U	Partial	1:62,500
Hayes and Landis (1964)	U	U	U	U	U	U	U	U	U	U	Partial	1:48,000
Gilluly (1956)	U	U	U	U	U	U	U	U	U	U	Partial	1:253,000 (approx.)
Heindl (1952)	U	U	U	U	U	U	U	U	U	U	Complete	1:453,000 (approx.)

Notes:

'U' indicates documentation was unavailable for ADWR to make a determination.

[1] Floodplain Holocene alluvium was identified and field mapped by other researchers referenced by authors.

[2] Age of floodplain alluvium shown on map was determined to be Holocene to Late Pleistocene.

[3] Age of floodplain alluvium shown on map was determined to be Quarternary and, therefore, may include Holocene and pre-Holocene (Pleistocene) deposits.

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CHAPTER 3: CONE OF DEPRESSION

This chapter describes the Department's proposed methodology for determining whether pumping from a well located outside of the jurisdictional subflow zone has created a cone of depression that intercepts and withdraws water from the subflow. Quoting with approval from the trial court, the Arizona Supreme Court stated that:

> "[w]ells located outside the lateral parameters of the defined 'subflow' zone" may be included in the adjudication if "it is proven that their 'cones of depression' reach the 'subflow' zone and the drawdown from the well affects the volume of surface and 'subflow' in such an appreciable amount that it is capable of measurement." In other words, the trial court ruled, a well may be subject to the adjudication if its " 'cone of depression' caused by its pumping has now extended to a point where it reaches an adjacent 'subflow' zone, and by continual pumping will cause a loss of such 'subflow' as to affect the quantity of the stream."

In re the General Adjudication of all Rights to use Water in the Gila River System and Source, 198 Ariz. 330, 342-343, 9 P.3d 1069, 1082-1083 (2000) *(Gila IV)*. The trial court requested that the Department include a cone of depression test in this report.

A cone of depression is a funnel-shaped area, often irregular, around a well where the withdrawal of groundwater by the well has lowered the water table. Determining the size of a well's cone of depression and how it changes over time with pumping is a relatively complex and data intensive task involving subsurface conditions. The Department believes that the following information needs to be known to determine whether a well currently outside of the jurisdictional subflow zone is pumping subflow by virtue of its cone of depression:

- *Distance* between the well and the jurisdictional subflow zone;
- *Time* that the well has been pumped and at what *discharge rate*;
- *Well construction* details; and
- Local *hydrogeologic conditions*.

With the exception of the distance between the well and the jurisdictional subflow zone, these conditions will often be either unknown or poorly known, and will need to be estimated. Conducting cone of depression tests requires numerous assumptions and considerable judgment and, in many cases, the test results will only provide a rough approximation of actual field conditions.

The courts have provided little guidance on how to proceed with cone of depression tests. In *Gila IV*, the Arizona Supreme Court left the development of a suitable test to the Department.

> The trial court did not attempt to establish a test for determining a well's cone of depression because the court lacked pertinent evidence on that issue. Instead, the court recognized that each well must be separately evaluated "to compute drawdown at the 'subflow' zone" and that 'whatever test ADWR finds is realistically adaptable to the field and whatever method is the least expensive and delay-causing, yet provides a high degree of reliability, should be acceptable."

198 Ariz. at 343, 9 P.3d at 1082. Although the Department has established a cone of depression test as anticipated by the Arizona Supreme Court, and as requested by the trial court, such a test has inherent difficulties and presents many challenges.

Before the Department describes its proposed methodology for conducting cone of depression tests, three related issues should be discussed. First, the Department does not currently have the resources to conduct cone of depression tests across wide areas of the Gila River adjudication. As noted by the court in *Gila IV*, a cone of depression test requires an evaluation of each well. Within the San Pedro River watershed alone, it is estimated that several hundred cone of depression tests would have to be performed. Even if the trial court were to proceed with the adjudication of smaller areas, such as subwatersheds, the Department would still face resource issues.

Second, results from cone of depression tests are time-sensitive. A well whose cone of depression does not intercept the jurisdictional subflow zone today may intercept it next week or several years from now. This is reason, along with the Department's limited resources, to wait to conduct cone of depression tests until a particular area is ready to be adjudicated as determined by the trial court.

And third, the methodology described in this chapter is limited to determining whether a well has a cone of depression that intercepts the jurisdictional subflow zone and is potentially pumping subflow. Additional data would be needed and new procedures developed to determine the *quantity* of appropriable water pumped from such a well. This would be a difficult task. As described in *Gila II*, most wells whose cones of depression have intercepted the jurisdictional subflow zone will not be pumping subflow alone, but rather, a mixture of subflow and tributary aquifer water.

> [I]f the cone of depression of a well has extended to the point that it intercepts a stream bed, it almost certainly will be pumping subflow. At the same time, however, it may be drawing water from the surrounding alluvium. Thus, part of its production may be appropriable subflow and part of it may not. Even though only a part of its production is appropriable water, that well should be included in the general adjudication.

In re the General Adjudication of all Rights to Use Water in the Gila River System and Source, 175 Ariz. at 382, 391, 857 P.2d 1236, 1245 (1993) (*Gila II*). Appendix F provides copies of three journal articles that further discuss streamflow depletion by wells and recent attempts by researches to quantify the effects. If the quantity of subflow that a well is pumping can be accurately quantified, a further issue may be whether this quantity has its own *de minimis* threshold.

Keeping the previous issues in mind, the Department proposes that the following steps be taken to conduct cone of depression tests:

- Determine well location, elevation, and distance from jurisdictional subflow zone;
- Determine pumping history;
- Determine frequency of pumping;
- Determine how the well was constructed;
- Characterize local hydrogeologic conditions;
- Define local aquifer properties;
- Construct a conceptual model of the aquifer system;
- Select a mathematical model;
- Input data and run a simulation using mathematical model;
- Analyze model output; and
- Determine whether a well should be adjudicated.

Although the Department recommends that cone of depression tests be conducted on a well-by-well basis, several of the steps listed above may be combined under suitable conditions and used for different wells in the same general area. These steps include characterization of local hydrogeologic conditions and aquifer properties, construction of a conceptual model, and selection of a mathematical model. Further discussion of these and the other steps proposed to conduct cone of depression tests is provided below.

3.1 WELL LOCATION, ELEVATION, AND DISTANCE FROM JURISDICTIONAL SUBFLOW ZONE

The well location should be determined by using a hand-held Global Position Satellite (GPS) unit. The distance between the well and the jurisdictional subflow zone can then be measured by plotting the well location and the edge of the jurisdictional subflow zone on a 7.5-minute series (1:24,000 scale) U.S. Geological Survey (USGS) topographic map using GIS technology. The well's elevation could then be estimated using coordinates from the GPS unit and Digital Elevation Model (DEM) software available through the USGS.

3.2 PUMPING HISTORY

The date that pumping began, and the average quantity of water pumped annually since that time, should be listed on the Statement of Claimant (SOC) filed by the well owner in the adjudication. If the SOC does not list the date that pumping began, the date of well completion could be used, as provided in the well driller's report filed with the Department. If the SOC does not list the quantity of water pumped, that amount may be estimated using one or a combination of the following:

- Pump capacity;
- Power records; and/or
- Claimed type of use.

Pump capacity is often listed in well registration documents and could be used to estimate the quantity pumped if the frequency of pumping were also known. Power records, if available, provide another means of estimating the quantity pumped, but this requires that the type of pump and the distance that the pump lifts the water be known. The quantity of water pumped could also be estimated based on the claimed type of use. For example, water use by an irrigation well could be estimated using records of cropped acreage and by assuming a water duty that is representative of the crop and irrigation system.

3.3 FREQUENCY OF PUMPING

Some wells, particularly those used in agricultural production, are only pumped during part of the year or during dry periods. Depending on the period that the well is used, the quantity of water pumped, and local aquifer conditions, the cone of depression may expand and contract over time.

For those wells believed not to have been pumped continuously, the Department recommends that the well owner be contacted for additional pumping information. Alternatively, power records could be used to determine seasonal water use. If further information is not available on the frequency of the well pumping, the Department proposes that it be assumed that the well has been pumped continuously throughout the year at a rate based on the annual pump volume.

3.4 WELL CONSTRUCTION

Well construction records (*i.e.* total well depth, screen or perforation zone, and location of annular seals) are needed to determine which geologic unit(s) supply water to the well. This information may be found in the well driller's report or other records maintained by the Department, such as construction reports filed in Active Management Areas (AMAs), and in applications filed with the Department for assured water supply (AWS) and water adequacy determinations, and for recharge purposes. However, even if available, these data may not necessarily be reliable. If reliable well construction records cannot be located, the Department proposes that it be assumed that the well is screened across its entire depth.

3.5 LOCAL HYDROGEOLOGIC CONDITIONS

To illustrate the hydraulic connection between the well and the jurisdictional subflow zone, hydrogeologic cross sections should be constructed that show the subsurface geology and location of saturated zones. In areas where the geologic units are highly stratified and/or laterally discontinuous, more cross sections may be needed to adequately illustrate the subsurface conditions. However, the number of cross sections that can be constructed and the area that they cover will ultimately be limited by data availability and resources.

The Department proposes that hydrogeologic cross-sections be constructed using available lithologic logs, geophysical measurements, and water level data from a variety of sources. These sources may include, but are not limited to:

- Well driller and construction reports (Department);
- AWS, water adequacy, and recharge program files (Department);
- Ground Water Site Inventory database (Department);
- Hydrographic Map Series (Department); and
- Published water supply and hydrogeologic studies (Department, USGS, Arizona Department of Environmental Quality, Arizona Geological Survey, Bureau of Land Management, United States Forest Service, and National Park Service).

3.6 LOCAL AQUIFER PROPERTIES

Aquifer properties for the geologic unit(s) that supply water to the well need to be defined next. In addition to the thickness and lateral extent of each unit, which would be based on the hydrogeologic cross sections, the unit's ability to transmit water under a hydraulic gradient (hydraulic conductivity) and yield water due to a change in head (storage coefficient) must be determined.

Adequate characterization of aquifer properties is perhaps the most difficult and the most important task in conducting cone of depression tests. As stated by T.N. Narasimhan (1998) at page 44 in his paper on the history of hydraulic characterization of aquifers, reservoir rocks, and soils:

> Looking purely from the viewpoint of science, it may appear as though what stands between us and satisfactory characterization is adequate data. Often we are limited by resource availability for data gathering, be it a research venture or engineering venture. Even in those situations where sufficient resources are available, one must consider whether the wells or boreholes themselves may compromise the integrity of the site. Constrained by these practical concerns, we need to recognize that the Earth's subsurface is difficult to assess. Consequently, our methods of hydraulic characterization are only capable of yielding estimates, and we function on the reasonable premise that the estimates become more reasonable with better information and fewer assumptions in the interpretation process.

A copy of Narasimhan's paper is provided in Appendix G.

Also in Appendix G is a copy of a 1996 water supply paper prepared by the USGS that describes how the hydraulic characteristics and yield of aquifers beneath the Ak-Chin Indian Community were determined. This work was conducted pursuant to the Ak-Chin Indian Community Water Rights Settlement Act, Public Law 95-328. Review of the USGS report demonstrates that, even when substantial time and resources are available to collect data, interpretation of aquifer conditions is not straightforward and requires considerable professional judgment.

To conduct cone of depression tests, the Department proposes that representative values for hydraulic conductivity and storage coefficient be taken from published water supply and hydrogeologic studies, preferably completed in the area where the well was drilled. If available, pump test data previously collected by the well owner, such as specific capacity data, may also be useful in defining local aquifer properties. Due to the spatial variability in aquifer properties, it may be necessary to define a reasonable range of values for each unit screened by the well.

3.7 CONCEPTUAL MODEL OF AQUIFER SYSTEM

To simulate how the cone of depression has formed and changed over time, a conceptual model of the aquifer system needs to be constructed. A conceptual model provides a verbal and graphical description of an aquifer system and the stresses on that system. The development of a conceptual model is usually the first step in the modeling process. The Department proposes that this simplified representation of an actual aquifer system be based on available information on local hydrogeologic conditions and aquifer properties and include the following components:

- Type of aquifer (unconfined, confined, or leaky);
- Aquifer geometry (uniform or irregular);
- Aquifer matrix (porous or fractured media, homogenous or heterogeneous, and isotropic or anisotropic);
- Aquifer boundaries (recharge, discharge, impermeable, constant head, water table, etc.);
- Mode of flow (2-dimensional horizontal or 3-dimensional);
- Initial flow conditions;
- Aquifer penetration by the well (fully or partially penetrating well); and
- History of well pumping (continuous or discontinuous, constant or variable rate).

The design of a conceptual model requires professional judgment and depends, to a large degree, on the availability of field data and the ingenuity of the modeler to estimate subsurface conditions based on limited or incomplete data.

3.8 MATHEMATICAL MODEL

The next step in the modeling process would be to transform the conceptual model into a mathematical model. Mathematical models are a set of flow equations whose solutions yield a simulation of the dynamic behavior of an aquifer system in response to aquifer stresses. Depending on how the flow equations are solved, these models can be broadly grouped into two categories, analytical or numerical.

The Department proposes that analytical models be used to evaluate a well's cone of depression where, based on the conceptual model, the aquifer system is less complex and the flow equations can be solved directly using calculus. It is important to note that the modeler can make several simplifying assumptions so that even relatively complex aquifer systems can be evaluated using analytical models. These simplifying assumptions are summarized by Walton (1989) and include corrections or adjustments to account for the following complexities:

- Irregular aquifer geometry (principle of equal area);

- Heterogeneous aquifers (incremental approximation technique);
- Anisotropic aquifers (principle of equivalent section);
- Aquifer boundaries (image well theory and the principle of superposition);
- Partially penetrating well (Hantush method); and
- Discontinuous pumping and variable pumping rates (principle of superposition).

Analytical models can be constructed relatively quickly using a variety of commercially available computer software. The Department recommends that the program THWELLS (version 4.01, 1996) be used for analytical modeling. This program was developed by P.K.M. van der Heijdge of the International Ground Water Modeling Center and is widely distributed. A copy of the manual for THWELLS is provided in Attachment H and includes a description of the program's development, verification, and testing and solutions to example problems. The Department currently uses THWELLS in evaluating applications for AWS designations and to conduct well impact analyses in AMAs.

The Department recommends that numerical models, instead of analytical models, only be used to evaluate the cone of depression of a well in special circumstances where, based on the conceptual model, the aquifer system is exceedingly complex and the flow equations can only be solved by recasting them in algebraic form. These recast equations are numerical approximations and their solutions are also approximations. Several computer programs have been written to solve numerical flow equations; the most widely used being the USGS finite-difference code MODFLOW. A fact sheet describing MODFLOW and a summary of the model's development are included in Appendix I. A copy of the software and additional information are available on-line at the USGS website http://water.usgs.gov/software/ground_water.html.

Although use of MODFLOW has been simplified by increases in computing speed and through development of user-friendly pre- and post-processing software, development of numerical models is still a very time consuming process that requires substantial field data to justify its use and to properly calibrate. The Department currently uses MODFLOW primarily to model impacts on large, regional aquifer systems. For most, if not all, cone of depression tests, the benefits of a more realistic numerical model would be outweighed by the difficulty and expense of collecting the data necessary to adequately define the numerical model and then run the computer simulation.

3.9 SIMULATIONS USING MATHEMATICAL MODEL

The data required to run the mathematical model would need to be compiled and entered into the selected computer program (THWELLS or MODFLOW). Depending on the complexity of the conceptual model, the model input may include several of the following:

- Model area (domain) and model grid;
- Location, aerial extent, and thickness of all aquifer and aquifer confining layers;
- Location and type of aquifer boundaries;
- Aquifer properties and their variation across the model domain;
- Initial position of the water table (unconfined aquifer) and/or potentiometric surface (confined aquifer) before pumping began (pre-development conditions);
- Location and quantity of natural aquifer recharge and discharge;
- Location and quantity of artificial recharge (*e.g.* infiltration of effluent and irrigation return flow);
- Location, depth, and open interval of cone of depression and image wells; and
- Rate and schedule of well pumping.

The model area and model grid would be determined by the complexity of the local aquifer system and the distance between the pumping well and the jurisdictional subflow zone. The spatial characteristics of the aquifer, confining layers, and aquifer boundaries would be based on hydrogeologic cross sections that the Department proposes be constructed in Section 3.5. Aquifer properties and their variability across the model area would be based, as proposed in section 3.6, on data from published water supply and hydrogeologic studies and, if available and reliable, on existing pump test data from the well. To determine the initial position of the water table and/or potentiometric surface before pumping began, the Department proposes to use the USGS predevelopment maps described in Chapter 2 and presented in Plates 1 through 3. Like aquifer properties, the occurrence of aquifer recharge and discharge between the pumping well and the jurisdictional subflow zone would be based on published water supply and hydrogeologic studies. Data on well location and construction would be collected following the procedures outlined in sections 3.1 and 3.4. And finally, the rate and schedule of well pumping would be based on information described in sections 3.2 and 3.3.

3.10 MODEL OUTPUT

Model output would be used to prepare a map that shows the simulated cone of depression and its relation to the jurisdictional subflow zone. If ranges of model inputs were evaluated, a series of cone of depression maps would be prepared. To evaluate whether the maps are reasonable, the Department proposes that, at a minimum, the simulated depth to water in the well be compared to past and current pumping levels, if available. Based on these comparisons, it may be necessary to adjust the model input (calibrate) to better reflect actual water level conditions and then rerun the mathematical model.

3.11 ADJUDICATION OF WELL

The Department proposes that a well be included in the adjudication only if, *at the time of the modeling*, two conditions are met. The first condition is that the simulated cone of depression has reached the edge of the jurisdictional subflow zone and drawdown at that point is greater than or equal to 0.1 foot, an amount that can be accurately measured in the field using standard water level measuring equipment. The second condition is that the water level in the well is *below* the water level in the jurisdictional subflow zone during pumping. If the water level in the well is *above* the water level in the jurisdictional subflow zone during pumping, the well cannot be pumping subflow.

It is important to remember that the accuracy of model simulations will in most, if not all, cases be far less accurate that the ability to measure drawdown in the field. Simulated water levels from even the most carefully calibrated MODFLOW models are typically no closer than $\pm$ 5 to 10 feet from the actual water levels measured in the field. And, unless water level data are available at the pumping well and at the edge of the jurisdictional subflow zone, it will be difficult to determine if the model simulations are overestimating or underestimating the true drawdown at these points.

3.12 THWELLS MODEL SIMULATIONS

This chapter concludes with two examples that demonstrate how THWELLS can be used to conduct cone of depression tests. The examples are hypothetical and the data used to run the model simulations were assumed to be readily available. As described earlier in this chapter, information needed to conduct cone of depression tests will often be unknown or only poorly known, requiring that data be estimated.

EXAMPLE 1

The first hypothetical example involves a municipal well located 10,000 feet (1.9 miles) upgradient of a jurisdictional subflow zone. The SOC filed by a water company who owns the well indicates it has been pumped since 1962 at a rate of 200 acre-feet per year. Assuming the well is pumped continuously, this equates to a discharge of approximately 124 gallons per minute (gpm).

Water adequacy documents filed with the Department include a completion log that shows that the well is 300 feet deep, sealed from 0 to 50 feet, and screened from 50 to 250 feet. Also in the Department's file were lithologic logs indicating that the well obtains water from a relatively uniform layer of silty sand that extends from the jurisdictional subflow zone to an area 3 miles upstream of the well. Based on predevelopment water level data from the USGS, the saturated thickness of the silty sand layer is about 200 feet and the municipal well completely penetrates the aquifer.

Previous work on a regional ground water model of the area found that the silty sand aquifer is relatively homogenous and isotropic with a hydraulic conductivity of 10 feet/day (ft/d) and a storage coefficient of 0.08. The unconfined aquifer is bounded at the base by low permeability clay deposits and at the top by a water table that slopes at a regional gradient of 0.2%.

Appendix J includes a printout of the input used in THWELLS to simulate the cone of depression around the municipal well and output from the model simulations. The model output shows that after 40 years of pumping, drawdown at the well is estimated to total about 23 feet. This compares favorably to the 27 feet of drawdown currently measured in the well. After only four years of pumping, the simulated drawdown at the edge of the jurisdictional subflow zone exceeds 0.1 feet, and the simulated water level in the pumping well was below the simulated water level at the edge of the jurisdiction subflow zone. Based on these model results, it is likely that the well is pumping subflow and should be included in the adjudication.

EXAMPLE 2

The second hypothetical example involves an irrigation well located 3,500 feet (0.7 miles) upgradient of a jurisdictional subflow zone. The SOC filed by a farmer who owns the well does not indicate how long the well has been pumped or at what rate. The farmer was contacted and it was learned that the well was installed in the spring of 1996 and has been used since that time to irrigate a small (1.5-acre) field of grapefruit trees. Meter records provided by the farmer indicate that the well is used throughout the year and the discharge has averaged 5 gpm, or 8.1 acre-feet per year.

The driller's report states that the irrigation well is 50 feet deep and screened from 30 to 50 feet. No information was provided on well seals, so it was assumed the well is unsealed. A log included in the driller's report indicates that the well obtains water from a 10-foot layer of "sand and gravel" overlain by 30 feet of "dry silt" and underlain by 10 feet of "tight clay". Based on predevelopment water level data from the USGS, the sand and gravel layer identified by the driller was previously completely saturated and the well completely penetrates this aquifer.

The only information on the hydraulic characteristics of the sand and gravel layer is found in a 1960 USGS water supply paper describing the availability of water in the region for agriculture. Pumping tests conducted by the USGS near the irrigation well found the aquifer has a hydraulic conductivity of 50 ft/d and a storage coefficient of 0.2. This unconfined aquifer is regionally extensive and bounded at the base by low permeability clay deposits and at the top by a water table that slopes at a regional gradient of 0.5%.

Appendix J includes a printout of the input used in THWELLS to simulate the cone of depression around the irrigation well and output from the model simulations. Model output shows that after six years of pumping, drawdown at the well is estimated to total 3.4 feet. This compares favorably to the 5 feet of drawdown currently measured in the well by the farmer. The simulated drawdown at the edge of the jurisdictional subflow zone never exceeds 0.1 feet after six years of pumping. Based on the model results, it appears that the well is not pumping subflow and should not be included in the adjudication at this time.

This chapter has presented a discussion of the steps required to implement a cone of depression test for wells located outside of the subflow zone. These steps are resource intensive and time sensitive. Accordingly, the Department recommends that they not be initiated until the trial court determines that a particular watershed or subwatershed is ready for adjudication.

CHAPTER 4: *DE MINIMIS* USES

This chapter describes methodologies for developing guidelines to determine whether a given well, though pumping subflow, has a *de minimis* effect on the river system, and further describes the Department's recommendations for addressing *de minimis* uses within the adjudication. Extensive proceedings have already been conducted by the special master in the San Pedro River watershed concerning *de minimis* uses, and the matter is now before the trial court for review. *In re Sands Group of Cases (W1-11-19) and Other Related Cases (Consolidated)* (Group 1 Cases). Discussed below are the special master's decision in the Group 1 Cases, and the Department's recommendations regarding *de minimis* uses.

4.1 GROUP 1 CASES

The Group 1 Cases have a long history beginning in 1993 when six consolidated cases were first organized for trial by Special Master Thorson. After a seven-day trial, and several months of post-trial briefing, the special master entered a memorandum decision in November 1994 (1994 Memorandum Decision). In February 1995, the special master granted the State of Arizona's motion for reconsideration, and modified the 1994 Memorandum Decision (1995 Modified Memorandum Decision). Between 1995 and 2001, objections were filed by the parties to the special master's 1994 and 1995 decisions in the Group 1 Cases. Objections were not filed by neighboring stockwatering, stockpond or domestic users, but rather by users below the mouth of the San Pedro River (1994 Memorandum Decision, p. 19). The matter was argued before the trial court on September 27, 2001 and now awaits decision.

In the special master's 1994 Memorandum Decision, the special master recommended definitions for stockwatering, stockpond and domestic *de minimis* uses. Because the vast majority of domestic uses are supplied by wells, the special master's definition for *de minimis* wells provides useful guidance. Although the Department disagrees with the special master's approach, the Department believes that the special master's definition of domestic *de minimis* use is acceptable. The appropriate definition will be decided by the trial court.

In the special master's 1994 Memorandum Decision, the special master engaged in a rigorous analysis to address the following questions:

> Are stockwatering, stockponds, or domestic water uses in the San Pedro River watershed *de minimis* in the context of the Gila River adjudication? If these uses are *de minimis*, what are the appropriate summary procedures for adjudicating them? What procedures should be followed to adjudicate any stockwatering, stockponds, or domestic uses not determined in this proceeding to be *de minimis* uses?

(1994 Memorandum Decision, p. 7.) The special master entered 64 findings of fact and 31 conclusions of law that addressed the total water supply of the San Pedro River watershed; the number of stockwatering, stockpond, and domestic uses within the watershed; the extent and impact of these uses on outflows from the watershed; the costs and benefits of a summary adjudication of these small uses; and appropriate procedures for summary adjudication of these uses. The special master concluded that the cumulative impact of depletions from stockwatering uses on flows at the mouth of the San Pedro River was a *de minimis* amount, but that neither the cumulative impact of depletions from stockponds nor the cumulative impact of depletions from domestic uses was a *de minimis* amount (1994 Memorandum Report, pp. 31, 33). However, based on the resources required to individually adjudicate these uses[1], as well as the difficulty of administering these uses post-decree, the special master further concluded that stockwatering, stockpond and domestic uses should be considered *de minimis*.

Part of the analysis undertaken by the special master included a determination of the cumulative impacts from stockponds, and the cumulative impacts from domestic uses, on the amount of water available at the mouth of the San Pedro River. Although not required for stockponds, the special master's analysis of domestic uses necessarily involved water supplied by wells. In Finding of Fact No. 22, the special master found that only about 3% of the domestic uses in the San Pedro River watershed were supplied by surface water, while 97% were supplied by wells (1994 Memorandum Decision, p.

[1] In Findings of Fact No. 58 and No. 59, the special master found that the pre-trial process alone resulted in the expenditure of $42,000 by the parties, and that it could require eleven years to complete a detailed, individual adjudication of each of the stockwatering, stockpond, and domestic uses in the San Pedro River watershed (1994 Memorandum Decision, pp. 29, 30). These uses totaled approximately 5,800 and comprised about 85% of all of the potential water rights included in the San Pedro River Watershed Hydrographic Survey Report (1994 Memorandum Decision, pp. 18, 26).

19). The calculations used by the special master to determine cumulative depletions from domestic uses have not been the subject of objections by the parties.

The special master's calculations in both the 1994 Memorandum Decision and the 1995 Modified Memorandum Decision relating to the amount of water available at the mouth of the San Pedro River have been the subject of considerable debate. The ratio between the amount of domestic use depletions and the amount of water available at the mouth of the San Pedro River led the special master to conclude that the cumulative impact of domestic uses could not be considered a *de minimis* amount. However, as indicated above, the special master concluded that these uses should still be subject to a summary adjudication process (1994 Memorandum Decision, p. 33).

In anticipation of trial in the *Group 1 Cases*, the special master requested that the Department prepare a technical report on the magnitude of *de minimis* uses in the San Pedro River watershed. In response to this request, the Department prepared a technical report entitled *Technical Report on De Minimis Adjudication of Domestic, Stockpond and Stockwatering Uses in the San Pedro Watershed* (ADWR, 1993), which was subsequently admitted into evidence at trial (1994 Memorandum Decision, p. 7). Based on information in the San Pedro River Watershed Hydrographic Survey Report (San Pedro HSR), the Department's analysis of impacts on the river system included approximately 3,000 domestic uses, 3% of which were supplied by surface water, with the remaining 97% supplied by domestic wells located throughout the entire San Pedro River watershed (ADWR, 1991). By assuming that withdrawals from these wells would have an instantaneous effect on reducing surface water supplies, the Department made a conservative calculation of the impact of domestic uses on the available water at the outflow of the watershed based on a undepleted flow analysis. This analysis involved a water budget that evaluated the impact of cultural uses on streamflow, and accounted for natural losses (evaporation and riparian use) that occur regardless of other uses. The Department concluded that the impact from domestic uses was only 1% of the watershed outflow amount.

The special master adopted the Department's 1993 Technical Report only in part. Although the special master accepted the Department's undepleted flow analysis for domestic uses in Finding of Fact No. 64, the special master did not agree with the Department's determination of the amount of water available at the mouth of the San

Pedro River (1994 Memorandum Decision, p. 31.) Instead of the 1% impact found by the Department, the special master concluded that there was between a 23% and 66% impact on water availability at the outflow of the watershed (1995 Modified Memorandum Decision, p. 14). The parties have challenged the special master's calculations supporting this conclusion.

Regardless of the impacts from domestic uses on the river system, the special master concluded that certain domestic uses should be treated as *de minimis*. The special master defined *de minimis* domestic uses as individual domestic uses for single residences, serving household purposes and associated outdoor activities on adjoining land not exceeding 0.2 acres. As part of the summary adjudication process, these *de minimis* uses would be quantified in an amount "not to exceed 1 acre-foot/year," and would be referred to as "self-supplied residential domestic rights."[2] Remaining domestic uses would be adjudicated separately in the normal course of the adjudication (1994 Memorandum Decision, p. 33). The special master's proposed definition of *de minimis* domestic uses with a uniform quantification has not been challenged by any of the parties. The Department also believes that this is an acceptable definition.

4.2 THE DEPARTMENT'S RECOMMENDATIONS

The special master's 1994 and 1995 decisions are currently before the trial court upon objections filed by the parties. It does not appear that any of the parties have challenged the special master's definition of *de minimis* uses, or the special master's determination that these *de minimis* uses should be summarily adjudicated with water rights characteristics. Based on a recent decision by the Arizona Supreme Court, the Department disagrees with the special master on the latter issue.[3]

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[2] The Department's undepleted flow analysis assumed a domestic use amount of 0.5 acre-feet per year, of which 80% was depleted (ADWR, 1993). Although the special master adopted the Department's undepleted flow amount, the special master disagreed with the Department's assumption regarding the quantity of each domestic use. The special master concluded that 1 acre-foot/year was the appropriate quantification amount (1994 Memorandum Decision, p. 33).

[3] Some of the parties raised related issues. See *e.g.* "United States Reply to Responses to Objections to Special Master's De Minimis Uses Report" (Jan. 11, 2001); "ASARCO Incorporated's Supplemental Objections to the Special Master's Memorandum Decision, Findings of fact, and Conclusions of Law for Group 1 Cases Involving Stockwatering, Stockponds, and Domestic Uses" (Sept. 6, 2001); "Response to Objections to Special Master's Report Re: Treatment of Stockwatering, Stockpond and Domestic Uses in the San Pedro River Watershed" (Nov. 9, 2000) filed by the Salt River Project Agricultural Improvement and Power District and the Salt River Valley Water Users' Association (SRP).

The special master's decision in 1994 to summarily adjudicate *de minimis* uses rather than to exclude them from the adjudication is called into question by an Arizona Supreme Court decision that was entered six years after the special master's first decision in the Group 1 Cases. By decision of 2000, the Arizona Supreme Court set forth three tests, including a subflow zone test, a cone of depression test, and a *de minimis* test, to determine whether a well should be included within the adjudication. The Court stated:

> All wells located within the lateral limits of the subflow zone are subject to this adjudication. In addition, all wells located outside the subflow zone that are pumping water from a stream or its subflow, as determined by DWR's analysis of the well's cone of depression, are included in this adjudication. *Finally, wells that, though pumping subflow, have a de minimus [sic] effect on the river system may be excluded from the adjudication based on rational guidelines for such an exclusion, as proposed by DWR and adopted by the trial court.*

In re the General Adjudication of all Rights to use Water in the Gila River System and Source, 198 Ariz. 330, 344, 9 P.3d 1069, 1083 (2000) (*Gila IV*) (emphasis added).

The above-quoted language reaffirms a prior Arizona Supreme Court decision. The Arizona Supreme Court previously stated:

> We believe that the trial court may adopt a rationally based exclusion for wells having a de minimis effect on the river system. Such a de minimis exclusion effectively allocates to those well owners whatever amount of water is determined to be de minimis. It is, in effect, a summary adjudication of their rights. A properly crafted de minimis exclusion will not cause piecemeal adjudication of water rights or in any other way run afoul of the McCarran Amendment. Rather, it could simplify and accelerate the adjudication by reducing the work involved in preparing the hydrographic survey reports and by reducing the number of contested cases before the special master.

In re the General Adjudication of all Rights to use Water in the Gila River System and Source, 175 Ariz. 382, 394, 857 P.2d 1236, 1248 (1993) (*Gila II*). Although the Court in *Gila II* stated that an exclusion of *de minimis* uses is "in effect, a summary adjudication of their rights," the Court also stated that it neither intended the Department to include those uses in the Department's hydrographic survey reports, nor intended that the special master litigate those uses as part of a contested case. Rather, the exclusion of *de minimis* uses would "simplify and accelerate the adjudication by reducing the work involved." Furthermore, such an exclusion would not "run afoul of the McCarran Amendment." The Department does not believe that the special master's approach to *de minimis* uses is consistent with *Gila II* and *Gila IV*.

In light of *Gila II* and *Gila IV*, the Department makes the following recommendations regarding *de minimis* uses. The Department recommends that *de minimis* domestic well uses be listed under a *de minimis* domestic use category in both the San Pedro HSR and in the court's decree.[4] The *de minimis* category would list the name of the present well owner, the well location to the nearest ¼ ¼ ¼ section, the type of use (domestic *de minimis*), the place of use, and the quantity of use. As long as these catalogued domestic uses continued to satisfy the definition of a *de minimis* use adopted by the trial court, these uses would not be subject to post-decree administration or enforcement.[5] In the Department's opinion, this approach would satisfy the directives of the *Gila II* and *Gila IV* that the adjudication be simplified and accelerated, while at the same time satisfying the McCarran Amendment.[6]

This chapter has set forth the Department's recommendation for addressing *de minimis* uses in the adjudication. The Department believes that the special master's definition of *de minimis* domestic uses is acceptable. However, based on decisions by the Arizona Supreme Court, the Department believes that these uses should not be summarily adjudicated with water rights characteristics. Rather, they should be excluded from the adjudication and catalogued in the decrees. The Department believes that this approach is consistent with both *Gila II* and *Gila IV*.

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[4] Another potential *de minimis* category would be for stockwatering uses supplied by wells. These wells were not addressed by the special master in the Group 1 Cases.

[5] In Finding of Fact No. 58, the special master stated: "Administration of individual domestic uses is generally not feasible in terms of making water available to downstream users." (1994 Memorandum Decision, p. 29.)

[6] The McCarran Amendment gives consent to suits against the United States in state court adjudications of rights to use water in a river system or other source. 43 U.S.C. ∍ 666(a).

CHAPTER 5: SUMMARY AND IMPLEMENTATION

In Chapters 2, 3, and 4 of this report, the Department describes methodologies for delineating the jurisdictional subflow zone within the San Pedro River watershed; for determining whether pumping by a well located outside the jurisdictional subflow zone has created a cone of depression that intercepts and withdraws water from the subflow zone; and, for developing guidelines to determine whether a given well, though pumping subflow, has a *de minimis* effect on the river system together with the Department's recommendations regarding *de minimis* uses. The Department summarizes these chapters below, and indicates how the methodologies described in those chapters may be implemented in the future.

CHAPTER 2

In Chapter 2, the Department describes the methodologies it proposes to use to delineate the jurisdictional subflow zone of the San Pedro River. These methodologies are summarized below.

As part of the preparation of this report, the Department has already conducted an extensive literature search to identify published streamflow maps that cover all or portions of the Gila River adjudication area. Based on this search, the Department identified two streamflow maps. One of the maps used was published by the U.S. Geological Survey (USGS) for predevelopment perennial reaches, and the other was published by the Arizona Game and Fish Department (AGFD) for recent perennial reaches. The Department proposes that these maps be combined to create a composite map of perennial streams. The Department was unable to identify published maps that depict predevelopment intermittent stream reaches. Therefore, the Department proposes to use only a map published by AGFD for recent intermittent stream reaches that may then be combined with the composite map of perennial reaches.

The Department also identified major and minor effluent fed streams based on information from the Arizona Department of Environmental Quality. However, the Department does not recommend that they be included on the streamflow maps. Two of the three major reaches are already included on the USGS predevelopment perennial map selected by the Department, and, for most other reaches, a hydraulic disconnect may often exist between the subflow and the stream.

The Department next proposes to identify and obtain copies of published surficial geology maps for the areas with perennial and intermittent streams. For the San Pedro River within the Sierra Vista subwatershed, the Department has already identified ten maps that delineate the lateral extent of the floodplain Holocene alluvium from map databases developed by the Arizona Geological Survey (AGS) and the USGS. The Department evaluated these maps and selected a map by Pool and Coes (1999) as the best available for this example.

For the last step, the Department attempted to determine the saturated portion of the floodplain Holocene alluvium. However, there is lack of readily available and reliable data that may be obtained by reasonable means to determine either the thickness of the alluvium, or the depth to water beneath the floodplain. Because of this limitation, and because streamflow conditions for predevelopment times have already been taken into account as part of the mapping steps described above, the Department recommends that the entire lateral extent of the saturated floodplain Holocene alluvium be assumed to be saturated for the purpose of delineating the jurisdictional subflow zone.

The Department believes that it has the necessary resources to determine the jurisdictional subflow zone using the steps outlined above. The Department anticipates that it would require approximately four to six months to implement these steps for *each* of the seven watersheds in the Gila River adjudication, including the San Pedro River watershed.

CHAPTER 3

In Chapter 3, the Department describes proposed methodologies for determining whether pumping from a well located outside of the jurisdictional subflow zone has created a cone of depression that intercepts and withdraws water from the subflow zone. Analysis of the size of a well's cone of depression and how it changes over time with pumping is a complex and data intensive task involving subsurface conditions that are difficult to determine.

The Department recommends that the following steps be undertaken. First, the well location, elevation, and distance from the subflow zone should be determined. The pumping history and frequency of pumping should then be established, and well construction records should be reviewed. Local hydrogeologic conditions and aquifer properties should also be established. After these steps are completed, a conceptual model of the aquifer system should be created which can then be transformed into an analytical or numerical mathematical model. For less complex aquifer systems, the Department recommends use of the computer program

THWELLS, an analytical model, and for more complex aquifer systems, the computer program MODFLOW, a numerical model. The Department further recommends that the model output be used to prepare a map depicting the simulated cone of depression and its relation to the jurisdictional subflow zone. If the model indicates that the drawdown at the edge of the jurisdictional subflow zone is greater than or equal to 0.1 foot, *and* the water level in the pumping well is below the water level in the jurisdictional subflow zone, then the Department recommends that the well be included in the adjudication.

The Department has limited resources to accomplish the steps described above. Ideally, these steps should be implemented on a well-by-well basis, but it may be possible to combine several of these steps and use them for different wells in the same general area. By using available data, and making certain assumptions based on professional judgment, the THWELLS analytical model could be run for each well, or group of wells in the same general area, within a watershed. For complex aquifer systems, the MODFLOW numerical model could also be used, but the necessary input data would be difficult and expensive to obtain.

Within the San Pedro River watershed alone, it is estimated that several hundred cone of depression tests would have to be performed. It has been the Department's experience that it takes one person working full time to make about 50 to 60 model runs using THWELLS in one year. Without sufficient resources, it could take several years to run the necessary models at the end of which the input data could be stale.

Because of the intensity of the resources required to conduct cone of depression tests, and because much of the data used for these tests is time sensitive, the Department recommends that the cone of depression analysis be delayed until a watershed is ready to be litigated. At that time, in order to provide timely analyses, additional resources will need to be devoted by either the Department or the parties.

CHAPTER 4

In Chapter 4, the Department describes the methodologies it proposes for developing guidelines to determine whether a given well, though pumping subflow, has a *de minimis* effect on the river system. This chapter also includes the Department's recommendations regarding *de minimis* uses.

The special master has already conducted extensive proceedings concerning guidelines related to *de minimis* uses, and the matter is currently before the trial court for review. *In re*

Sands Group of Cases (W1-11-19) and Other Related Cases (Consolidated) (Group 1 Cases). In the Group 1 Cases, the special master concluded that three categories of uses should be summarily adjudicated as *de minimis* uses, including stockwatering from streams, stockponds, and domestic uses. The majority of the domestic uses are supplied by wells. The special master defined a *de minimis* domestic use as an individual domestic use for single residences that serves household purposes and associated outdoor activities on adjoining land not exceeding 0.2 acres with a quantification of not to exceed 1.0 acre-foot per year. Because this definition has not been challenged by the parties, the Department recommends that the trial court use this definition as a guideline to determine *de minimis* uses.

The Department further recommends that *de minimis* uses be listed under a *de minimis* domestic use category in both the San Pedro River Watershed Hydrographic Survey Report and in the court's decree. The list would include the name of the present well owner, the well location, the type of use, the place of use, and the quantity of use. Under the Department's proposal, these uses would not receive a decreed water right and would not be subject to post-decree administration or enforcement.

The Department recommends that *de minimis* uses supplied by wells be identified within each watershed after the Department determines the lateral extent of the subflow zone using the steps described in Chapter 2 of this report. In order to implement this process, the Department would obtain appropriate remote sensing imagery, review existing records regarding well location and uses supplied by those wells, and conduct field investigations as necessary. Assistance in obtaining additional information from well owners could be obtained through a public notice process.

The Department recommends initiating these steps as each watershed is designated by the trial court for litigation. The time required would be a function of the number of domestic wells within each watershed. The Departments estimates that the following amounts of time would be required for each of the watersheds within the Gila River adjudication:

- Two to four months for the Upper Agua Fria River watershed;
- Two to four months for the Upper Santa Cruz River watershed;
- Four to six months for the San Pedro River watershed;
- Four to six months for the Upper Salt River watershed;
- Six to ten months for the Verde River watershed;

- Six to twelve months for the Lower Gila River watershed; and
- Ten to twelve months for the Upper Gila River watershed; and

IMPLEMENTATION SEQUENCE

In this report, the Department has described proposed methodologies for determining the jurisdictional subflow zone, for applying a cone of depression test, and for addressing *de minimis* uses. For each watershed, the Department recommends that the jurisdictional subflow zone be identified first, followed by the identification of those uses which qualify as domestic *de minimis* uses. This will minimize the number of wells that will be subject to the costly and resource intensive cone of depression test, which depends upon time-sensitive data. The identification of *de minimis* uses and implementation of the cone of depression test should only be implemented when the watershed is ready to be litigated, and sufficient resources have been identified to conduct the necessary analyses in a timely manner in advance of the commencement of litigation.

W. Patrick Schiffer, Acting Chief Counsel (Bar No. 004256)
Janet L. Ronald (Bar No. 011963)
Deputy Counsel
Arizona Department of Water Resources
Legal Division
500 North 3rd Street
Phoenix, AZ 85004
(602) 417-2420

IN THE SUPERIOR COURT OF THE STATE OF ARIZONA

IN AND FOR THE COUNTY OF MARICOPA

IN THE GENERAL ADJUDICATION OF ALL RIGHTS TO USE WATER IN THE GILA RIVER SYSTEM AND SOURCE	)	W-1 (Salt) W-2 (Verde) W-3 (Upper Gila) W-4 (San Pedro Consolidated **ARIZONA DEPARTMENT OF WATER RESOURCES' NOTICE OF SUBFLOW TECHNICAL REPORT ERRATA**

DESCRIPTIVE SUMMARY: The Arizona Department of Water Resources hereby files a notice of errata contained within its subflow technical report filed on March 29, 2002.

NUMBER OF PAGES: Two.

DATE OF FILING: April 1, 2002.

The Arizona Department of Water Resources hereby provides notice of the errata contained within its report entitled "Subflow Technical Report, San Pedro River Watershed" that was filed on March 29, 2002. The following errata include typographical errors and misidentification of some of the appendices in the text.

Page 23. "Appendix F" should be "Appendix E." **Page 27.** "Appendix G" should be "Appendix F." **Page 29**: "Attachment H" should be "Appendix G." **Page 29.** "Appendix I" should be "Appendix H." **Page 31.** In the fourth line from the bottom of the page, the word "that" should be "than." **Page 32**. "Appendix J" should be "Appendix I." **Page 33.** "Appendix

J" should be "Appendix I." **Page 40.** In footnote 6, the correct citation is "43 U.S.C. § 666(a)." **Page 45.** The words "extra; and" should be "extra."

DATED this 1st day of April, 2002.

ARIZONA DEPARTMENT OF WATER RESOURCES

W. Patrick Schiffer, Acting Chief Counsel
Janet L. Ronald, Deputy Counsel
500 North 3rd Street
Phoenix, Arizona 85004
(602) 417-2420

ORIGINAL of the foregoing mailed on the 1st day of April, 2002 to:

Clerk of the Superior Court
Maricopa County
Attention: Water Case
601 W. Jackson Street
Phoenix, AZ 85003

COPIES of the foregoing mailed on the 1st day of April, 2002 to the court-approved mailing list and to:

Honorable Eddward Ballinger, Jr.
Judge of the Superior Court
101 W. Jefferson
Phoenix, AZ 85003-2212

Special Master George A. Schade, Jr.
Arizona General Stream Adjudication
Arizona State Court Building
1501 W. Washington St., Suite 228
Phoenix, AZ 85007

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